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Arias Drake et al.

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(54) **SYSTEMS AND METHODS FOR
AUTOMATIC FORMAL METASTABILITY
FAULT ANALYSIS IN AN ELECTRONIC
DESIGN**

(58) **Field of Classification Search**
CPC .. G06F 17/50; G06F 17/5022; G06F 17/5045;
G06F 17/505; G06F 17/5031;
(Continued)

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(57) **ABSTRACT**

The present disclosure relates to a computer-implemented method for use in an electronic design. The method may include receiving, using at least one processor, an electronic design and analyzing the electronic design. The method may further include generating one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design. The method may also include generating, based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer.

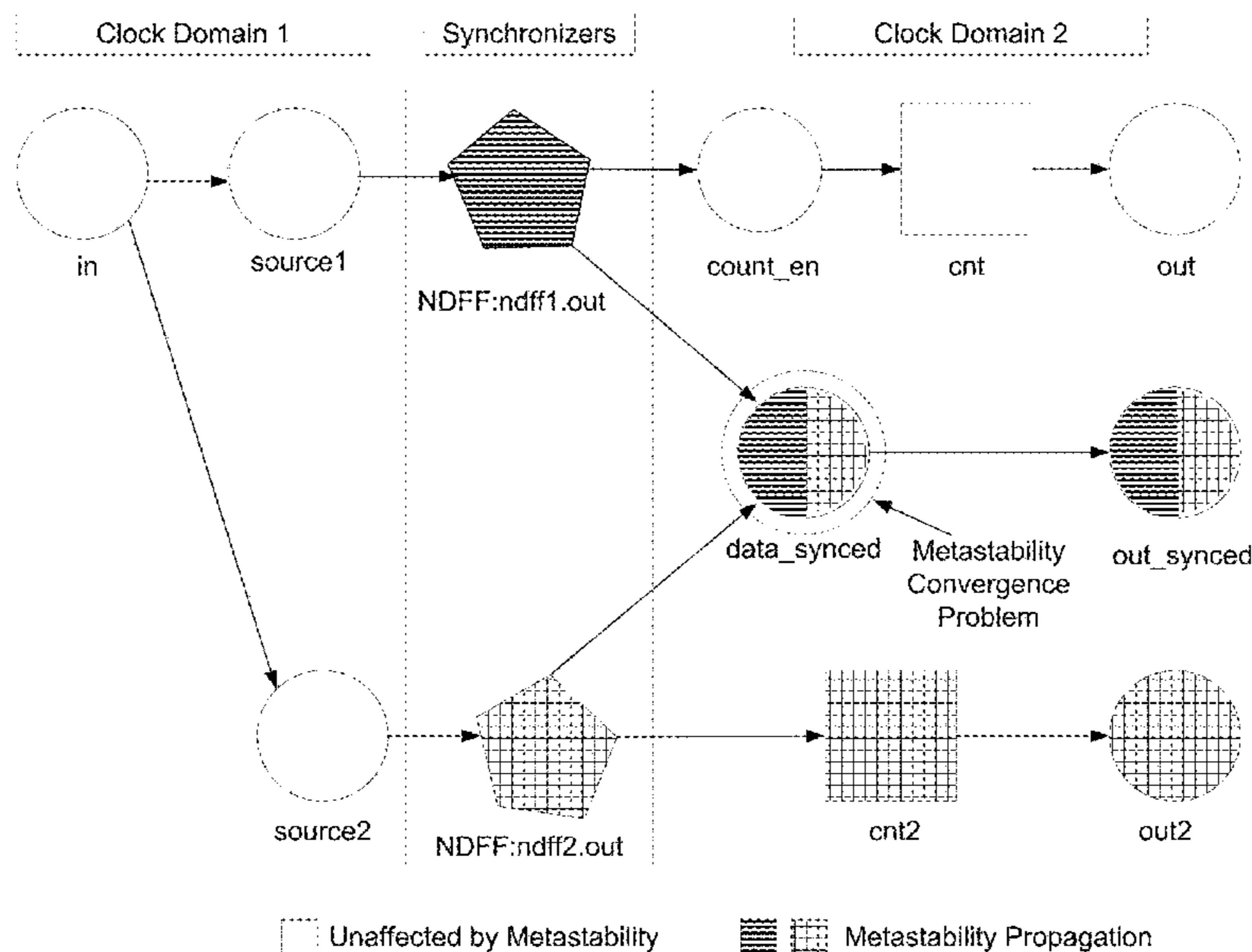
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12 Claims, 4 Drawing Sheets



(58) **Field of Classification Search**
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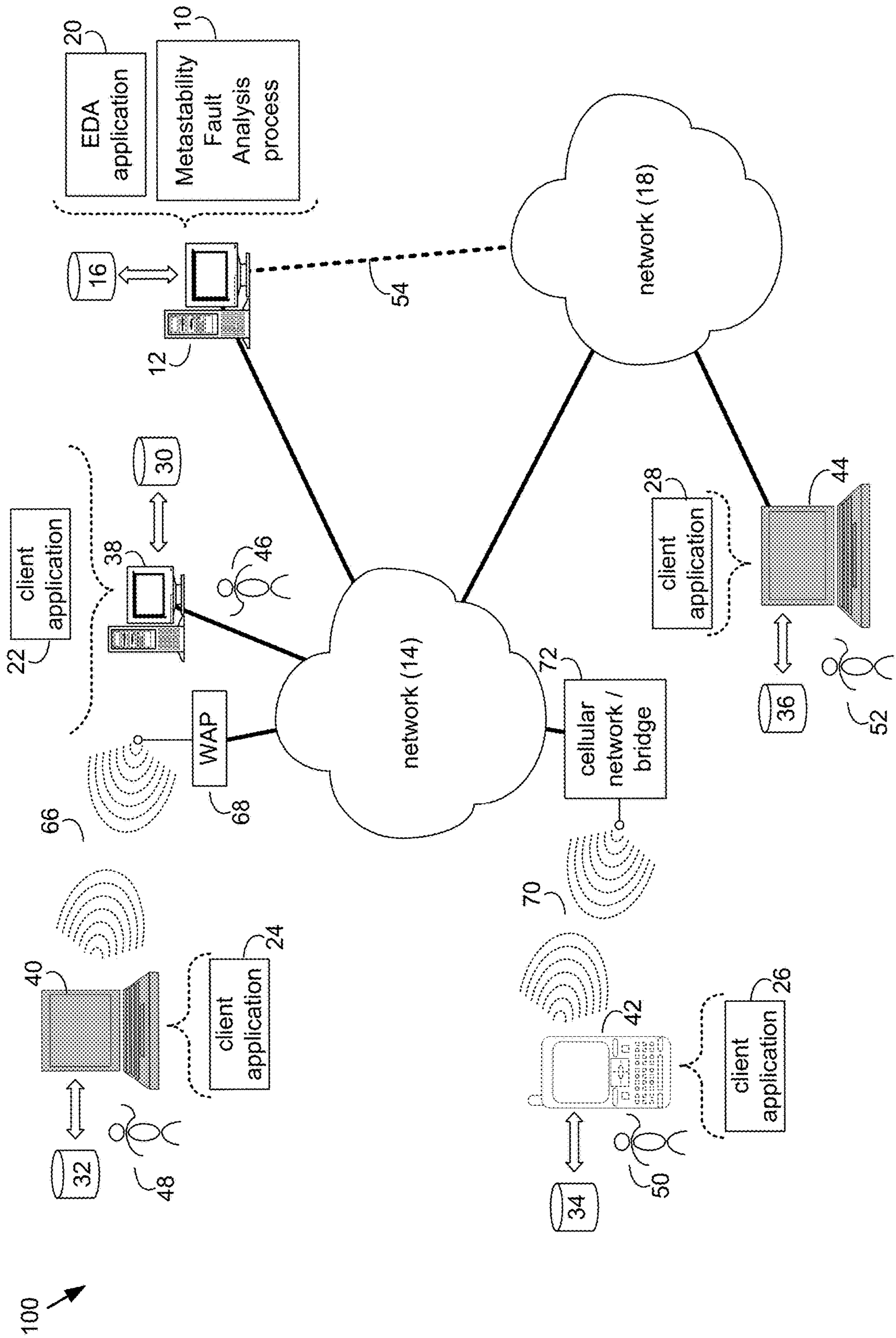


FIG. 1

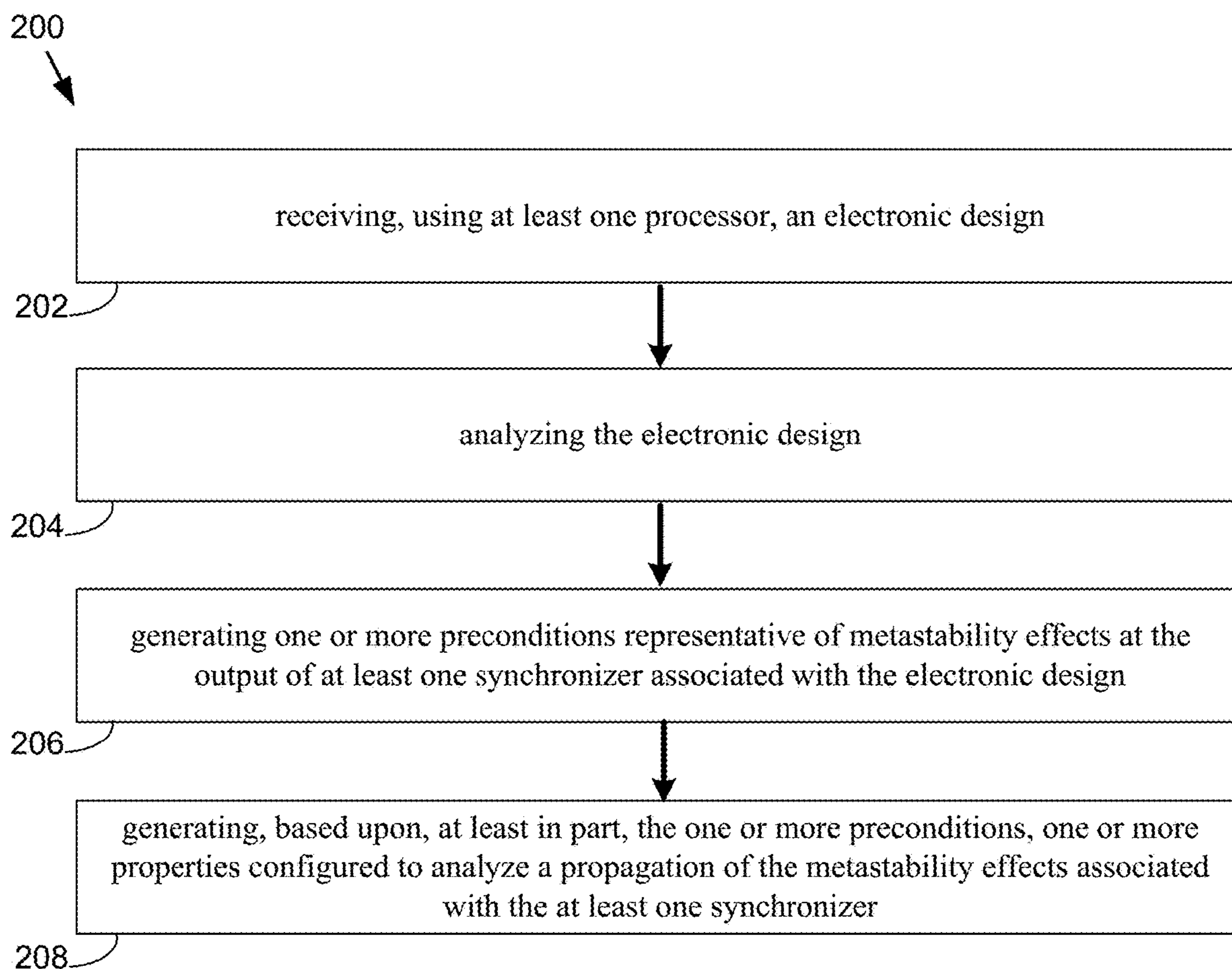


FIG. 2

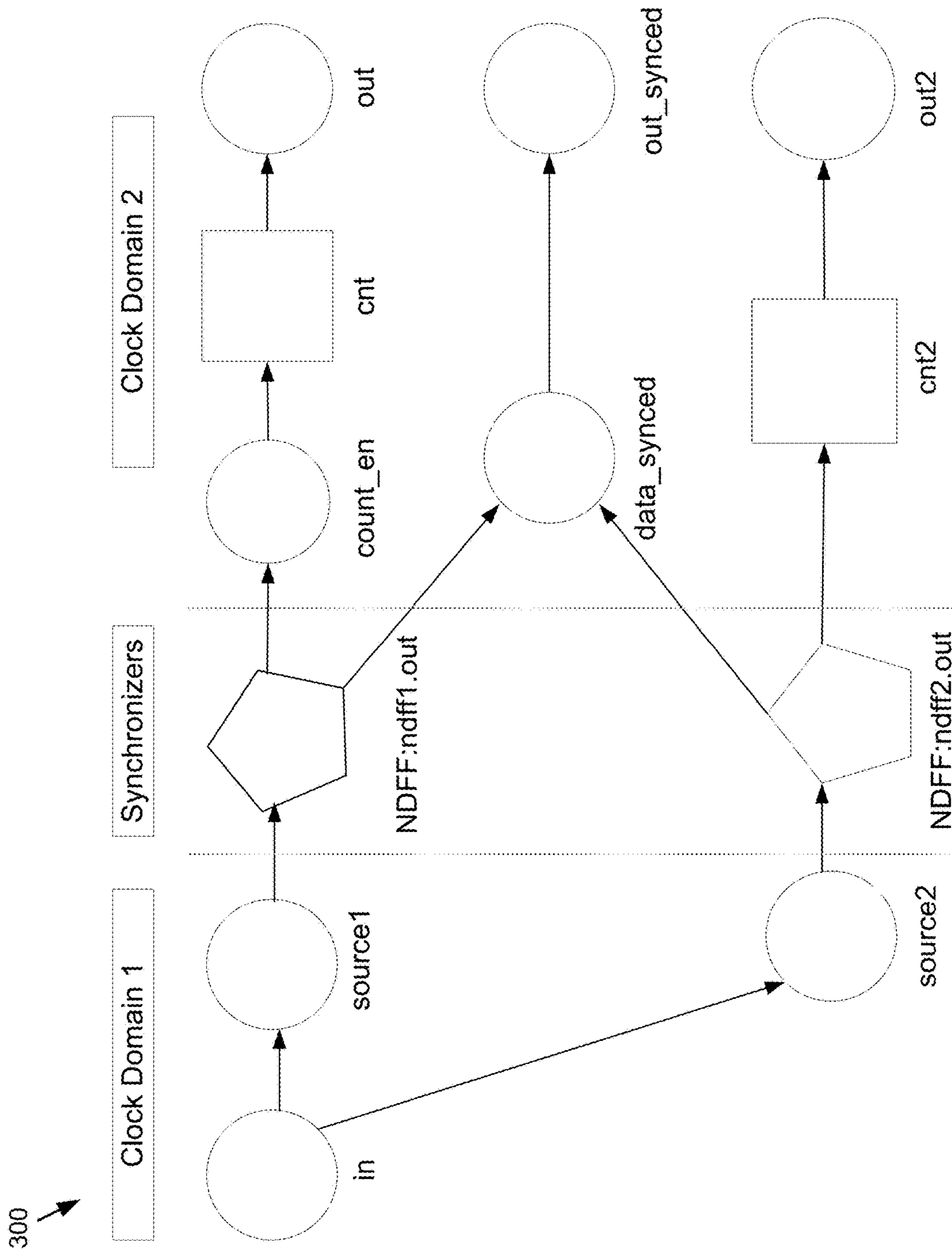


FIG. 3

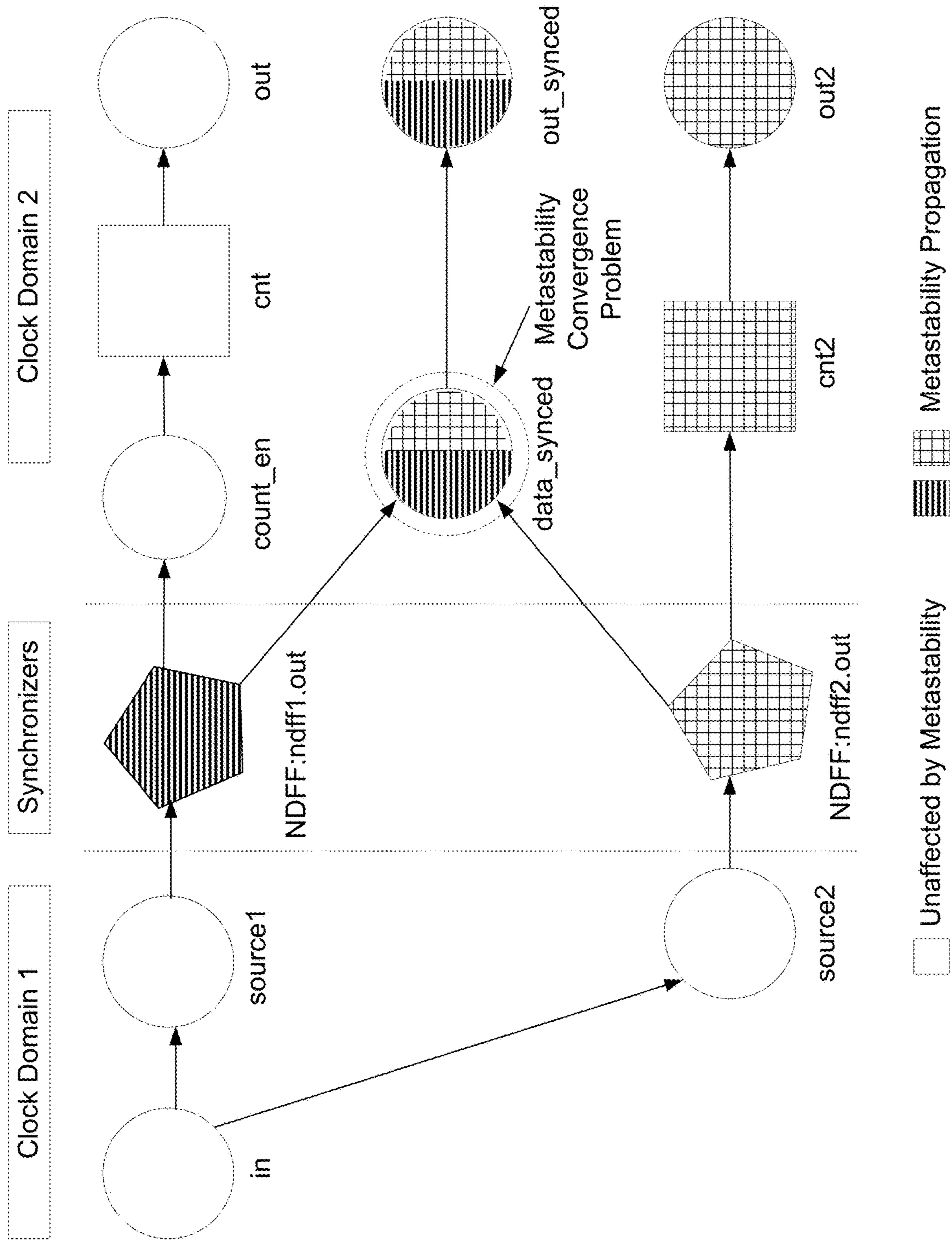


FIG. 4

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**SYSTEMS AND METHODS FOR
AUTOMATIC FORMAL METASTABILITY
FAULT ANALYSIS IN AN ELECTRONIC
DESIGN**

FIELD OF THE INVENTION

The present disclosure relates to electronic design techniques, and more specifically, to a system and method for automatic formal metastability fault analysis of an electronic design.

DISCUSSION OF THE RELATED ART

Simulation-based verification can be used to debug metastability convergence problems but, at present, metastability coverage metrics offered by simulation are not reliable enough to provide the level of confidence demanded by users. Metastability convergence analysis in formal verification could be done by manually adding properties to model both the effects of metastability and its propagation through the design.

Users are not confident that current metastability coverage metrics for simulation-based verification offer the necessary level of confidence to guarantee that every metastability occurrence and convergence path in the design are exercised. In the case of formal tools, a number of properties should be added by the user to model both the effects of metastability and its propagation through the design. Without them, solving the problem would suffer from the state-explosion problem, thus decreasing performance and scalability. However, the level of knowledge and configuration that generating the properties requires from the user becomes a significant obstacle.

SUMMARY

In one or more embodiments of the present disclosure, a computer-implemented method for use in an electronic design is provided. The method may include receiving, using at least one processor, an electronic design and analyzing the electronic design. The method may further include automatically generating one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design. The method may also include automatically generating, based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer.

One or more of the following features may be included. In some embodiments, analyzing the propagation of the metastability effects may include analyzing a fan-out cone associated with the at least one synchronizer. The method may include visually displaying at least one of the metastability effects at an annotated graph. In some embodiments, the annotated graph may be configured to display the at least one synchronizer and at least one clock domain. The annotated graph may be configured to display at least one of a safe area, a node reached by metastability effects, and a metastability convergence point. The annotated graph may be configured to display at least one node and wherein the at least one node corresponds to a flip-flop, an input port, or an output port. The electronic design may be a clock-domain crossing design.

In some embodiments, a computer-readable storage medium having stored thereon instructions that when

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executed by a machine result in one or more operations is provided. Operations may include receiving, using at least one processor, an electronic design and analyzing the electronic design. Operations may further include automatically generating one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design. Operations may also include automatically generating, based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer.

One or more of the following features may be included. In some embodiments, analyzing the propagation of the metastability effects may include analyzing a fan-out cone associated with the at least one synchronizer. Operations may include visually displaying at least one of the metastability effects at an annotated graph. In some embodiments, the annotated graph may be configured to display the at least one synchronizer and at least one clock domain. The annotated graph may be configured to display at least one of a safe area, a node reached by metastability effects, and a metastability convergence point. The annotated graph may be configured to display at least one node and wherein the at least one node corresponds to a flip-flop, an input port, or an output port. The electronic design may be a clock-domain crossing design.

In one or more embodiments of the present disclosure, a system is provided. The system may include a computing device configured to receive, using at least one processor, an electronic design. The at least one processor further configured to analyze the electronic design and automatically generate one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design. The at least one processor may be further configured to automatically generate, based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer.

One or more of the following features may be included. In some embodiments, analyzing the propagation of the metastability effects may include analyzing a fan-out cone associated with the at least one synchronizer. The at least one processor may be further configured to visually display at least one of the metastability effects at an annotated graph. In some embodiments, the annotated graph may be configured to display the at least one synchronizer and at least one clock domain. The annotated graph may be configured to display at least one of a safe area, a node reached by metastability effects, and a metastability convergence point. The annotated graph may be configured to display at least one node and wherein the at least one node corresponds to a flip-flop, an input port, or an output port.

Additional features and advantages of embodiments of the present disclosure will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of embodiments of the present disclosure. The objectives and other advantages of the embodiments of the present disclosure may be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

It is to be understood that both the foregoing general description and the following detailed description are exem-

plary and explanatory and are intended to provide further explanation of embodiments of the invention as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included to provide a further understanding of embodiments of the present disclosure and are incorporated in and constitute a part of this specification, illustrate embodiments of the present disclosure and together with the description serve to explain the principles of embodiments of the present disclosure.

FIG. 1 is a system diagram depicting aspects of the metastability fault analysis process in accordance with an embodiment of the present disclosure;

FIG. 2 is a flowchart depicting operations consistent with the metastability fault analysis process of the present disclosure;

FIG. 3 is a diagram depicting aspects of the metastability fault analysis process in accordance with an embodiment of the present disclosure; and

FIG. 4 is a diagram depicting aspects of the metastability fault analysis process in accordance with an embodiment of the present disclosure.

DETAILED DESCRIPTION

In Clock-Domain Crossing (CDC) designs, even structurally and functionally correct synchronizers cannot completely mitigate the effects of metastability due to the unpredictability in the exact cycle that they will sample their inputs. The existence of convergence paths in certain topologies can make this uncertainty translate into erroneous behaviors.

Analyzing metastability convergence in formal verification requires the user to write properties to model both the effects of metastability and its propagation through the design. This requires significant knowledge from the user, and usually suffers from the state-explosion problem. In addition, debugging metastability convergence problems requires a considerable effort, due to the difficulty of focusing on relevant information.

Accordingly, embodiments of the present disclosure may be configured to enable formal analysis to automatically identify metastability convergence problems without relying on user properties. Embodiments of the present disclosure may be configured to automatically extract a set of preconditions to represent metastability effects at the output of identifiable synchronizers. These preconditions significantly improve performance and scalability. Based on the preconditions, the metastability fault analysis process described herein may recursively generate properties to analyze the propagation of metastability effects through the synchronizers fan-out cones, again improving performance and scalability. As is discussed in further detail hereinbelow, results may be shown in an annotated graph, where safe areas, nodes which are reached by metastability effects and metastability convergence points are clearly indicated. In this way, automatic metastability formal fault analysis using synchronizer information is a scalable, formal based, fully automated and easy to debug flow to identify where metastability might really be a problem in a CDC design.

Reference will now be made in detail to the embodiments of the present disclosure, examples of which are illustrated in the accompanying drawings. The present disclosure may, however, be embodied in many different forms and should not be construed as being limited to the embodiments set forth herein. Rather, these embodiments are provided so that

this disclosure will be thorough and complete, and will fully convey the concept of the disclosure to those skilled in the art.

As will be appreciated by one skilled in the art, the present disclosure may be embodied as a method, system, or computer program product. Accordingly, the present disclosure may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, the present disclosure may take the form of a computer program product on a computer-usable storage medium having computer-usable program code embodied in the medium.

Any suitable computer usable or computer readable medium may be utilized. The computer readable medium may be a computer readable signal medium or a computer readable storage medium. A computer-usable, or computer-readable, storage medium (including a storage device associated with a computing device or client electronic device) may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer-readable medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device. In the context of this document, a computer-usable, or computer-readable, storage medium may be any tangible medium that can contain, or store a program for use by or in connection with the instruction execution system, apparatus, or device.

A computer readable signal medium may include a propagated data signal with computer readable program coded embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electromagnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device. Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

Computer program code for carrying out operations of the present disclosure may be written in an object oriented programming language such as Java, Smalltalk, C++ or the like. However, the computer program code for carrying out operations of the present disclosure may also be written in conventional procedural programming languages, such as the "C" programming language or similar programming languages. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through a local area network (LAN) or a wide area network (WAN), or

the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

The present disclosure is described below with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the disclosure. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

These computer program instructions may also be stored in a computer-readable memory that can direct a computer or other programmable data processing apparatus to function in a particular manner, such that the instructions stored in the computer-readable memory produce an article of manufacture including instructions which implement the function/act specified in the flowchart and/or block diagram block or blocks.

The computer program instructions may also be loaded onto a computer or other programmable data processing apparatus to cause a series of operational steps to be performed on the computer or other programmable apparatus to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide steps for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

Referring to FIG. 1, there is shown a metastability fault analysis process 10 that may reside on and may be executed by server computer 12, which may be connected to network 14 (e.g., the Internet or a local area network). Examples of server computer 12 may include, but are not limited to: a personal computer, a server computer, a series of server computers, a mini computer, and a mainframe computer. Server computer 12 may be a web server (or a series of servers) miming a network operating system, examples of which may include but are not limited to: Microsoft® Windows® Server; Novell® NetWare®; or Red Hat® Linux®, for example. (Microsoft and Windows are registered trademarks of Microsoft Corporation in the United States, other countries or both; Novell and NetWare are registered trademarks of Novell Corporation in the United States, other countries or both; Red Hat is a registered trademark of Red Hat Corporation in the United States, other countries or both; and Linux is a registered trademark of Linus Torvalds in the United States, other countries or both.) Additionally/alternatively, the metastability fault analysis process may reside on and be executed, in whole or in part, by a client electronic device, such as a personal computer, notebook computer, personal digital assistant, or the like.

The instruction sets and subroutines of metastability fault analysis process 10, which may include one or more software modules, and which may be stored on storage device 16 coupled to server computer 12, may be executed by one or more processors (not shown) and one or more memory modules (not shown) incorporated into server computer 12. Storage device 16 may include but is not limited to: a hard disk drive; a solid state drive; a tape drive; an optical drive;

a RAID array; a random access memory (RAM); and a read-only memory (ROM). Storage device 16 may include various types of files and file types including but not limited, to hardware description language (“HDL”) files and/or any suitable files that may be associated with an electronic design.

Server computer 12 may execute a web server application, examples of which may include but are not limited to: Microsoft IIS, Novell Webserver™, or Apache® Webserver, that allows for HTTP (e.g., HyperText Transfer Protocol) access to server computer 12 via network 14 (Webserver is a trademark of Novell Corporation in the United States, other countries, or both; and Apache is a registered trademark of Apache Software Foundation in the United States, other countries, or both). Network 14 may be connected to one or more secondary networks (e.g., network 18), examples of which may include but are not limited to: a local area network; a wide area network; or an intranet, for example.

Server computer 12 may execute an electronic design automation (EDA) application (e.g., EDA application 20), examples of which may include, but are not limited to those available from the assignee of the present application. EDA application 20 may interact with one or more EDA client applications (e.g., EDA client applications 22, 24, 26, 28). EDA application 20 may be referred to herein as a design tool.

Metastability fault analysis process 10 may be a stand alone application, or may be an applet/application/script that may interact with and/or be executed within EDA application 20. In addition/as an alternative to being a server-side process, the metastability fault analysis process may be a client-side process (not shown) that may reside on a client electronic device (described below) and may interact with an EDA client application (e.g., one or more of EDA client applications 22, 24, 26, 28). Further, the metastability fault analysis process may be a hybrid server-side/client-side process that may interact with EDA application 20 and an EDA client application (e.g., one or more of client applications 22, 24, 26, 28). As such, the metastability fault analysis process may reside, in whole, or in part, on server computer 12 and/or one or more client electronic devices.

The instruction sets and subroutines of EDA application 20, which may be stored on storage device 16 coupled to server computer 12 may be executed by one or more processors (not shown) and one or more memory modules (not shown) incorporated into server computer 12.

The instruction sets and subroutines of EDA client applications 22, 24, 26, 28, which may be stored on storage devices 30, 32, 34, 36 (respectively) coupled to client electronic devices 38, 40, 42, 44 (respectively), may be executed by one or more processors (not shown) and one or more memory modules (not shown) incorporated into client electronic devices 38, 40, 42, 44 (respectively). Storage devices 30, 32, 34, 36 may include but are not limited to: hard disk drives; solid state drives, tape drives; optical drives; RAID arrays; random access memories (RAM); read-only memories (ROM), compact flash (CF) storage devices, secure digital (SD) storage devices, and a memory stick storage devices. Examples of client electronic devices 38, 40, 42, 44 may include, but are not limited to, personal computer 38, laptop computer 40, mobile computing device 42 (such as a smart phone, netbook, or the like), notebook computer 44, for example. Using client applications 22, 24, 26, 28, users 46, 48, 50, 52 may access EDA application 20 and may allow users to e.g., utilize metastability fault analysis process 10.

Users **46, 48, 50, 52** may access EDA application **20** directly through the device on which the client application (e.g., client applications **22, 24, 26, 28**) is executed, namely client electronic devices **38, 40, 42, 44**, for example. Users **46, 48, 50, 52** may access EDA application **20** directly through network **14** or through secondary network **18**. Further, server computer **12** (e.g., the computer that executes EDA application **20**) may be connected to network **14** through secondary network **18**, as illustrated with phantom link line **54**.

The various client electronic devices may be directly or indirectly coupled to network **14** (or network **18**). For example, personal computer **38** is shown directly coupled to network **14** via a hardwired network connection. Further, notebook computer **44** is shown directly coupled to network **18** via a hardwired network connection. Laptop computer **40** is shown wirelessly coupled to network **14** via wireless communication channel **66** established between laptop computer **40** and wireless access point (e.g., WAP) **68**, which is shown directly coupled to network **14**. WAP **68** may be, for example, an IEEE 802.11a, 802.11b, 802.11g, Wi-Fi, and/or Bluetooth device that is capable of establishing wireless communication channel **66** between laptop computer **40** and WAP **68**. Mobile computing device **42** is shown wirelessly coupled to network **14** via wireless communication channel **70** established between mobile computing device **42** and cellular network/bridge **72**, which is shown directly coupled to network **14**.

As is known in the art, all of the IEEE 802.11x specifications may use Ethernet protocol and carrier sense multiple access with collision avoidance (e.g., CSMA/CA) for path sharing. The various 802.11x specifications may use phase-shift keying (e.g., PSK) modulation or complementary code keying (e.g., CCK) modulation, for example. As is known in the art, Bluetooth is a telecommunications industry specification that allows e.g., mobile phones, computers, and personal digital assistants to be interconnected using a short-range wireless connection.

Client electronic devices **38, 40, 42, 44** may each execute an operating system, examples of which may include but are not limited to Microsoft Windows, Microsoft Windows CE®, Red Hat Linux, or other suitable operating system. (Windows CE is a registered trademark of Microsoft Corporation in the United States, other countries, or both).

Referring now to FIG. 2, a method **200** consistent with an embodiment of metastability fault analysis process **10** is provided. The method may include receiving (**202**), using at least one processor, an electronic design and analyzing (**204**) the electronic design. The method may further include automatically generating (**206**) one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design. The method may also include automatically generating (**208**), based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer.

As discussed above, embodiments of the present disclosure may be configured to enable formal analysis to automatically identify metastability convergence problems without relying on user properties. Embodiments of the present disclosure may be configured to automatically extract a set of preconditions to represent metastability effects at the output of identifiable synchronizers. These preconditions significantly improve performance and scalability. Based on the preconditions, the metastability fault analysis process described herein may recursively generate properties to

analyze the propagation of metastability effects through the synchronizers fan-out cones, again improving performance and scalability. As is discussed in further detail hereinbelow, results may be shown in an annotated graph, where safe areas, nodes which are reached by metastability effects and metastability convergence points are clearly indicated. In this way, automatic metastability formal fault analysis using synchronizer information is a scalable, formal based, fully automated and easy to debug flow to identify where metastability might really be a problem in a CDC design.

In the example pseudocode below the following definitions may apply:

Let D be the design provided by the user.

Let G be a graph representation of D, where the nodes are flops, input and output ports and the edges are combinational logic between flops.

Let S be the set of synchronizers identified in G.

For a given synchronizer s belonging to S, let out(s) be the data output node of the synchronizer, where metastability might appear, and let out(S) be the set of all synchronizers' data output nodes.

Let NC be the set of destination nodes of CDC pairs not covered by any synchronizer.

Let M be the set of metastability injection nodes, defined as the union of sets out(S) and NC.

Let METASTABILITY(s) be a condition which is true whenever out(s) is affected by the uncertainty due to metastability.

Let PROPS be an initially empty set of properties.

Let p(i→j) denote a property which is true if there exists a functional path in G from node i to node j, and which is false if such a path does not exist.

One possible example of pseudocode is provided below, however it should be noted that this is provided merely by way of example:

```

II Initialization
build G from D
find CDC pairs in G
find S and NC in G
build M as out(S) U NC
foreach m in M:
  II Create initial property to be proven
  foreach neighbor n of m in G:
    if m E out ( S ) :
      add property p(m->n) with METASTABILITY (s) as the
      precondition to PROPS
    else:
      add property p(m->n) with $changed(input(m)) as the
      precondition to PROPS
  endforeach
II Prove remaining properties and generate new ones until PROPS
is empty while PROPS is not empty:
p(m->j) = next property from PROPS
prove p(m->j)
if p(m->j) passes:
  add label of node in to node j
  foreach neighbor n of j in G:
    if m E out ( S ) :
      add property p(m->n) with METASTABILITY (s)
      as the precondition to PROPS
    else:
      add property p(m->n) $changed(input(m)) as the
      precondition to PROPS
  endforeach
endif
endwhile
endforeach
show labeled graph G

```

As shown in the definitions and the pseudocode provided above, given a design including clock-domain crossing pairs

and a set S of identifiable synchronizers, embodiments of metastability fault analysis process **10** may be configured to automatically build the set of nodes M where metastability can be originated, by considering both the synchronizers' data output nodes ($out(S)$) and the destination flops of CDC pairs not covered by a synchronizer (NC).

In addition, for each synchronizer $s \in S$, embodiments of metastability fault analysis process **10** may automatically set up a condition $METASTABILITY(s)$, which states the conditions under which the uncertainty due to metastability is present at the synchronizer's data output node $out(s)$. In the case of CDC pairs not covered by a synchronizer, a change in the destination flop's input may be used as the condition for metastability.

Embodiments of metastability fault analysis process **10** may then analyze whether the effects of metastability may propagate from M to the design's outputs. This may be accomplished through an incremental process for each node m in M , where the formal engine may be fed with automatically generated properties that check for the existence of functional paths between m and the nodes in its fan-out cone, given the appropriate precondition ($METASTABILITY(s)$ or change in the destination flop's input).

Referring again to FIGS. 3-4, in some embodiments, circles may represent signals (e.g., either outputs of flops, or top-level input or output ports in the design). Pentagons may represent synchronizers. They are a collapsed view of the set of nodes that compose each synchronizer. Squares may represent design instances. They are a collapsed view of the hierarchy of instances and nodes included inside them.

In some embodiments, metastability fault analysis process **10** may begin with an unlabeled graph, as that shown in FIG. 3. In the example, set S is composed of synchronizers $ndff1$ and $ndff2$, and set NC is empty. For each synchronizer s in S , the condition $METASTABILITY(s)$ may be automatically generated. In the example, conditions $METASTABILITY(ndff1)$ and $METASTABILITY(ndff2)$ would be generated and available to be used.

In some embodiments, the next step may involve the creation of the following properties, which may use $METASTABILITY(s)$ as a precondition:

$p(ndff1.out \rightarrow count_en)$: Functional path exists from $ndff1.out$ to $count_en$, given that $METASTABILITY(ndff1)$

$p(ndff1.out \rightarrow data_synced)$: Functional path exists from $ndff1.out$ to $data_synced$, given that $METASTABILITY(ndff1)$

$p(ndff2.out \rightarrow cnt2)$: Functional path exists from $ndff2.out$ to $cnt2$, given that $METASTABILITY(ndff2)$

$p(ndff2.out \rightarrow data_synced)$: Functional path exists from $ndff2.out$ to $data_synced$, given that $METASTABILITY(ndff2)$

In some embodiments, those properties may then be fed to the formal engines, which may return the following results in the example:

$ndff1.out$ to $count_en$: FALSE

$ndff1.out$ to $data_synced$: TRUE

$ndff2.out$ to $cnt2$: TRUE

$ndff2.out$ to $data_synced$: TRUE

As a result of the passing (TRUE) ones, the following new properties would be created:

$ndff1.out$ to out_synced : Functional path exists from $ndff1.out$ to out_synced , given that $METASTABILITY(ndff1)$

$ndff2.out$ to out_synced : Functional path exists from $ndff2.out$ to out_synced , given that $METASTABILITY(ndff2)$

$ndff2.out$ to $out2$: Functional path exists from $ndff2.out$ to $out2$, given that $METASTABILITY(ndff2)$

Again, those properties would be fed to the formal engines, which may return the following results:

$ndff1.out$ to out_synced : TRUE

$ndff2.out$ to out_synced : TRUE

$ndff2.out$ to $out2$: TRUE

Since all considered paths reached the design outputs, no more properties are generated and the process may end.

In some embodiments, the result may be the annotated graph shown in FIG. 4. Signals in which the metastability coming from $ndff1.out$ is able to propagate are labeled in a first color (e.g. depicted by the horizontal hatching in FIG. 4), while ones coming from $ndff2.out$ are labeled in a different color (e.g. depicted by the cross-hatching in FIG. 4). Nodes for which no functional path exists, like $count_en$, are simply kept without a label.

Finally, nodes which are affected by metastability being propagated from more than one source (like $data_synced$) may be labeled using the colors of the different source synchronizers. These nodes represent metastability convergence problems.

During this process, and referring also to FIG. 4, nodes in M 's fan-out cone may be labeled as either unaffected by metastability effects (shown in white in FIG. 4), or subject to the effects of metastability originated in some node $m \in M$ (shown in cross or horizontal hatching in FIG. 4). Metastability convergence points are therefore indicated as nodes suffering the effects of metastability from more than one source (shown as mixed cross/horizontal hatching nodes in FIG. 4).

This automated process may end when the effects of metastability are propagated from every $m \in M$ to either the design's outputs or some frontier that prevents further propagation of metastability effects.

Embodiments of metastability fault analysis process **10** may be configured to utilize formal technology to provide the level of metastability coverage demanded by users. In addition, by automating a series of tasks in an innovative way, embodiments of metastability fault analysis process **10** may leverage formal analysis to identify metastability convergence problems without relying on user properties, thus removing this burden from the user.

Embodiments of metastability fault analysis process **10** may provide numerous advantages over existing technologies. In contrast to the simple structural checks for the detection of convergence problems, embodiments disclosed herein are based on functional checks, therefore reducing the number of false violations reported. Additionally and/or alternatively, the teachings of the present disclosure are formal based, in opposition to the simulation based approaches, so any safe node is guaranteed not to suffer from the modeled metastability effect. Unlike other formal based solutions, embodiments of metastability fault analysis process **10** do not rely on user properties, so it can be easily configurable and fully automated. In addition to not requiring user properties, the use of the annotated graph as a visualization tool, thus providing better usability.

Embodiments of metastability fault analysis process **10** may reduce the number of false violations reported, since it is based on functional checks. Some embodiments may be configured to identify situations where a synchronizer is generating metastability but its effects may not propagate beyond a certain frontier. Embodiments of metastability fault analysis process **10** may be efficient and scalable, thanks to the automatic definition of $METASTABILITY(s)$ preconditions for every supported synchronizer, which

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diminish the state-explosion problem. Embodiments included herein may be easily configurable and fully automated, since it does not rely on user properties. Every property required to model metastability effects and their propagation are recursively and automatically generated. The use of a labeled graph as a visualization tool significantly helps the user to identify and debug metastability convergence problems.

In some embodiments, EDA application **20** and/or metastability fault analysis process **10** may support a variety of languages and/or standards. EDA application **20** may support one or more software extensions and may be used in conjunction with one or more EDA tools such as those available from the Assignee of the subject application.

As used in any embodiment described herein, the terms “circuit” and “circuitry” may include, for example, singly or in any combination, hardwired circuitry, programmable circuitry, state machine circuitry, and/or firmware that stores instructions executed by programmable circuitry. It should be understood at the outset that any of the operations and/or operative components described in any embodiment herein may be implemented in software, firmware, hardwired circuitry and/or any combination thereof. Embodiments of the present disclosure may be incorporated in whole or in part into any design tools.

It will be apparent to those skilled in the art that various modifications and variations can be made in the embodiments of the present disclosure without departing from the spirit or scope of the present disclosure. Thus, it is intended that embodiments of the present disclosure cover the modifications and variations provided they come within the scope of the appended claims and their equivalents.

What is claimed is:

1. A computer-implemented method for use in a formal verification of an electronic design comprising:

- receiving, using at least one processor, a clock-domain crossing electronic design;
- analyzing the electronic design;
- automatically generating a set of nodes where metastability can be originated;
- automatically generating one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design;
- automatically generating, based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer; and
- visually displaying at least one of the metastability effects and one or more unaffected areas at an annotated graph configured to display the at least one synchronizer and at least one clock domain.

2. The computer-implemented method of claim **1**, wherein analyzing the propagation of the metastability effects includes analyzing a fan-out cone associated with the at least one synchronizer.

3. The computer-implemented method of claim **1**, wherein the annotated graph is configured to display at least one of an area unaffected by a metastability issue, a node reached by metastability effects, and a metastability convergence point.

4. The computer-implemented method of claim **1**, wherein the annotated graph is configured to display at least one node and wherein the at least one node corresponds to a flip-flop, an input port, or an output port.

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5. A non-transitory computer-readable storage medium having stored thereon instructions that when executed by a machine result in the following operations for use in a formal verification of an electronic design:

- receiving, using at least one processor, a clock-domain crossing electronic design;
- analyzing the electronic design;
- automatically generating a set of nodes where metastability can be originated;
- automatically generating one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design;
- automatically generating, based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer; and
- visually displaying at least one of the metastability effects and one or more unaffected areas at an annotated graph configured to display the at least one synchronizer and at least one clock domain, wherein the annotated graph displays a node unaffected by metastability in a first manner and a node affected by metastability in a second manner distinct from the first manner.

6. The computer-readable storage medium of claim **5**, wherein analyzing the propagation of the metastability effects includes analyzing a fan-out cone associated with the at least one synchronizer.

7. The computer-readable storage medium of claim **5**, wherein the annotated graph is configured to display at least one of an area unaffected by a metastability issue, a node reached by metastability effects, and a metastability convergence point.

8. The computer-readable storage medium of claim **5**, wherein the annotated graph is configured to display at least one node and wherein the at least one node corresponds to a flip-flop, an input port, or an output port.

9. A system for a formal verification of an electronic design comprising:

- a computing device configured to receive, using at least one processor, a clock-domain crossing electronic design, the at least one processor further configured to analyze the electronic design and automatically generate a set of nodes where metastability can be originated, the at least one processor further configured to automatically generate one or more preconditions representative of metastability effects at the output of at least one synchronizer associated with the electronic design, the at least one processor further configured to automatically generate, based upon, at least in part, the one or more preconditions, one or more properties configured to analyze a propagation of the metastability effects associated with the at least one synchronizer, wherein analyzing the propagation of the metastability effects includes analyzing a fan-out cone associated with the at least one synchronizer, the at least one processor further configured to visually display the metastability effects and one or more unaffected areas at an annotated graph configured to display the at least one synchronizer and at least one clock domain.

10. The system of claim **9**, wherein analyzing the propagation of the metastability effects includes analyzing a fan-out cone associated with the at least one synchronizer.

11. The system of claim **9**, wherein the annotated graph is configured to display at least one of an area unaffected by a

metastability issue, a node reached by metastability effects, and a metastability convergence point.

12. The system of claim 9, wherein the annotated graph is configured to display at least one node and wherein the at least one node corresponds to a flip-flop, an input port, or an output port.

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